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Research on unsymmetrical loading effect induced by the secondary mining in the coal pillar

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Abstract

The coal pillar is usually subject to mining influence on both sides.The loading distribution on coal pillar is unsymmetrical under the unilateral influence.Its own bearing characteristic is closely related to the surrounding rock structure.To determine the width of the pillar in coal mine, the dynamic stability of the pillar should be taken into account besides the consideration of the maximum static loading capacity. Theoretical calculating formula of the plastic zone of the coal pillar induced by one-sided mining is presented according to the limiting equilibrium theory in this paper. The unsymmetrical loading effect during the advancing process of the mining is analyzed through the field monitoring by the deployment of the stress sensors in the pillar along the longitudinal direction. The method to determine the proper width of the coal pillar is presented at last.

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Keywords: width of the coal pillar; mine stress monitoring; unsymmetrical loading; influence by mining

1. Unsymmetrical loading induced by one-sided mining

The loading capacity of the coal pillar, which is influenced by the mining process from both sides, is closely related with the structure of adjacent rock. If the influence of the mining is not considered, the stress in the coal pillar with rather large width shows symmetrical saddle distribution due to the existing of elastic zone in the middle of the pillar. If the width of the coal pillar is much smaller, the stress in the

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both sides of the pillar shows superimposed phenomenon and it can lead to the failure of the pillar due to the cut through of the fracture zones on both sides of the pillar. Obviously, the greater width of the coal pillar is positive to the stability of the pillar, but much greater width is uneconomic for the rational use of the coal resources.

Influenced by the one-sided mining, the loading distribution on the coal pillar is unsymmetrical. There are three phases for the stress development in the pillar and they are termed as influence pre-zone, influence zone and influence back-zone. On the side of mining, roof of the pillar will collapse consequently, thus the loading distribution varied seriously and it can lead to the dynamic failure of the pillar.

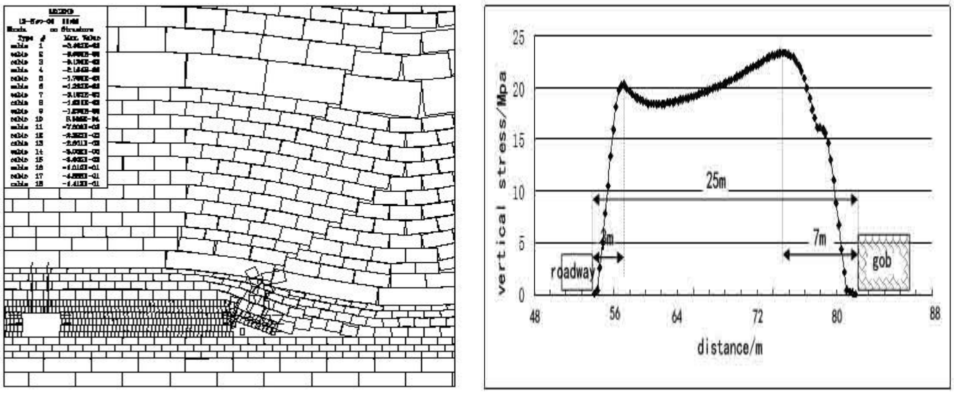

Fig. 1 unsymmetrical loading distribution influenced by one-sided mining

Unsymmetrical loading refers to the loading acting on the pillar by the roof shows unsymmetrical by the pillar's axis in the case of one-sided mining as shown in figure 1, the stress on the side of stope is much greater than the other side, which is close to the tunnel. The condition of symmetrical loading distribution in the coal pillar only can be found in the horizontal coal seam without tectonic stress and influence of the mining process. In most cases, it generally shows unsymmetrical. The determination of the width of the pillar in a traditional way only considers the symmetrical loading on it. The influences caused by the stope advancement are neglected can it can lead to the stress distribution in reality is far from the theoretical calculating results. So the determination of the width of the pillar should be based on the unsymmetrical loading and exact position of the peak stress induced by one-sided mining.

2. The characteristics of the plastic zone induced by one-sided mining

Because the length of the coal pillar is much greater than its width, the stress in the coal pillar can be simplified and analyzed as a plane strain problem in the transverse direction. Mohr-Coulomb strength principle can be satisfied along the interface between the pillar body and its roof/floor in the limiting equilibrium zone as $\tau_{xy} = -(c_0 + \sigma_y \tan\phi_0)$. In the formula, σ_y and τ_{xy} refer to the normal and tangential stress acting along the interface between the pillar body and its roof/floor.

The stress calculating model of the plastic zone in the coal pillar is shown in figure 2. In this figure, K is the maximum stress concentration factor; γ is the average density of the overlying rock strata; H is the depth of mining; M is the thickness of the coal seam; Px is the restraining force in the x direction; c_0 and

ϕ_0 are the cohesion and internal friction angle along the interface between coal and roof/floor; x_0 is the yielding width of the coal pillar; $\bar{\sigma}_x$ is the average stress in x direction at the position $x=x_0$.

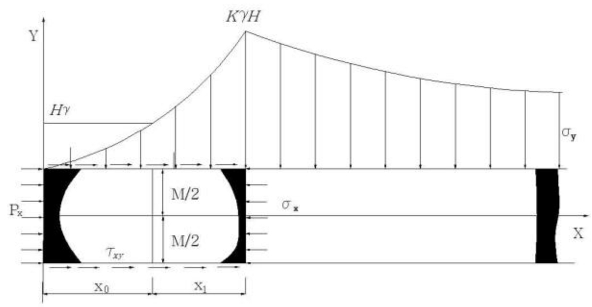

Fig. 2 Calculating model of the plastic zone in the coal pillar

The limiting equilibrium can be satisfied along the interface between the coal pillar and roof/floor when the coal body is forced out from that area. Assuming the coal body is homogenous and continuous, the stresses in the coal body can satisfy the following differential equilibrium equations according to the calculating model in figure 2.

$$\begin{cases} \dfrac{\partial \sigma_x}{\partial x} + \dfrac{\partial \tau_{xy}}{\partial y} = 0 \\ \dfrac{\partial \sigma_y}{\partial y} + \dfrac{\partial \tau_{xy}}{\partial x} = 0 \\ \tau_{xy} = -(c_0 + \sigma_y \tan \phi_0) \end{cases}$$

Along the interface ($x=x_0$) between fracture zone and plastic zone, limiting equilibrium state can be reached under the combined acting of in situ vertical stress and horizontal stress. Mohr-Coulomb strength principle is satisfied as the following equation.

$$\sigma_3 = \frac{1-\sin\phi}{1+\sin\phi}\sigma_0 - \frac{2c\cos\phi}{1+\sin\phi}$$

Where, ϕ and c are the internal friction angle and cohesion of the coal body respectively; in situ vertical stress $\sigma_0 = \lambda\gamma$ H. The stress boundary condition can be described using the following equations:

$$\sigma_y\Big|_{x=x_0} = \sigma_0 = \gamma H$$

$$\bar{\sigma}_x\Big|_{x=x_0} = \sigma_3 = \lambda\gamma H$$

Where, λ is the coefficient of horizontal pressure.

If the whole yielding zone is isolated, the resultant stress in x direction should equal to zero as following equation.

$$M\lambda\sigma_x\Big|_{x=x_0} - 2\int_0^{x_0} \tau_{xy}\,dx - P_x M = 0$$

According to the basic equations and stress boundary conditions mentioned above, width of the fracture zone in the pillar can be derived as the following equation.

$$x_0 = \frac{M\lambda}{2\tan\phi_0}\ln\left[\frac{\lambda H + \dfrac{c_0}{\tan\phi_0}}{\dfrac{c_0}{\tan\phi_0} + \dfrac{P_x}{\lambda}}\right] \quad (1)$$

Same method can be used to derive the width of the plastic zone in the pillar as the following equation.

$$x_1 = \frac{M\lambda}{2\tan\phi_0}\ln\left[\frac{K\lambda H + \dfrac{c_0}{\tan\phi_0}}{\dfrac{c_0}{\tan\phi_0} + \dfrac{\sigma_3}{\lambda}}\right] \quad (2)$$

The stress in the peripheral coal pillars will redistribute with the advancement of the mining stope. Fracture zone, plastic zone, elastic zone and in situ stress zone can be formed consequently from the pillar edge to the deep zone. The stress of the adjacent rock will transmit gradually to the deep zone. The elastic zone, plastic zone and fracture zone can reflect three different development phases of elastic deformation, yielding and failure of the coal pillars. The range of the fracture zone and plastic zone can be gained according to the limiting equilibrium condition influenced by one-sided mining.

The coal pillar of 25 m in width at the mining stope with 275 m in length at LiuTa mine, the width of fracture zone and yielding zone influenced by one-sided mining can be calculated as 0.8 m and 6.0 m respectively if using the related theory above. The mining stress concentration factor of the pillar is 1.3.

3. Monitoring and analysis of the unsymmetrical loading

In order to verify the stress distribution in the coal pillars influenced by one-sided mining, some instruments were installed in the pillars of 08 mining stope of LiuTa mine. Stress sensors were installed into 7 horizontal deep drill holes with an average depth of 11 m and space interval of 3m. The data reading process lasted around 5 months.

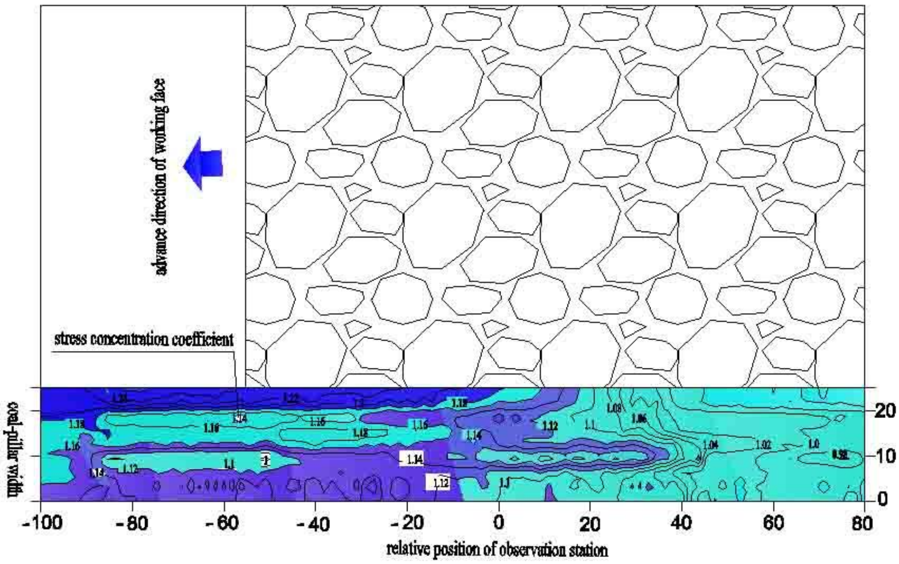

Fig. 3 Stress distribution diagram in the coal pillar relative to the survey station

The stress distribution diagram exhibits that the stresses show not very obvious increment at the distance of 80 m away from the stope. The stress shows obvious increment from the distance of 60m away from the stope and the lateral stress concentration factor even can reach around 1.1. The value of the stress reached the peak value after the stope passed survey station 20 m and the lateral stress concentration can reach around 1.2. The stress in the coal pillar showed decreasing trend after the stope passed survey station 80 m. The width affected by peak stress is around 80m and the stress concentration factor varied in the range of 1.08-1.24. According to the data from the survey station, unsymmetrical loading effect is very obvious and the peak value of the stope side is much greater than the other side of the pillar. There is a relatively low stress zone of 8 m in width between two positions with peak stress values, the maximum stress concentration factor of the stope side and tunnel side are 1.24 and 1.08 respectively.

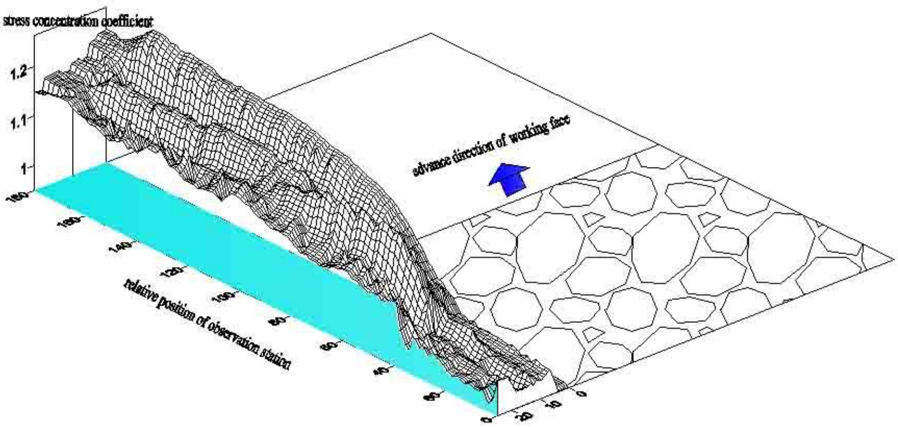

Fig. 4 Variation of the vertical stress diagram in 3D relative to the stope

In figure 4, unsymmetrical saddle-shaped stress distribution can be found in the coal pillar, the stress concentration factor close to the stope side is much greater than the other side. This result is mainly caused by the serious movement of the aged roof and corresponding fractures occurred in it. There is a relatively low stress zone of 8 m in width existing between the two peak stress values on the saddle-shaped curved face. So the pillar width of 25 m adopted currently is too conservative and the width of 20 m is recommended for the proper protection.

4. Conclusions

(1) For the determination of the width of the coal pillar, besides the considering of the static maximum loading capacity, the dynamic stability of the coal pillar also need to be considered. That means the stress variation during the whole process of the mining. According to the stress survey on site, the variation of the mining stress lagged behind the advancement of the stope, the stress normally reached the peak value after stope passed a certain distance.

(2) Unsymmetrical loading effect can be found in the coal pillars, the stress shows unsymmetrical saddle shape caused by one-sided mining, the stress concentration factor of the gob side is much greater

than the other side, so it is proper to consider the unsymmetrical loading factor when determining the width of the coal pillar.

(3) Stress sensors are deployed in the coal pillars along the longitudinal direction for the studying the stress development in the coal pillars during the whole process of the mining. It is meaningful for the determination of the proper width of the pillars and the instruction of the related support design.

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